

# Review of Side Friction Factors in Highway Curve Design of Higher Speed Freeways

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**Abstract:** This paper presents a review of the conventional curve design theory and its applicability to SMART highway that is a new type of freeway with higher design speed of 130-160 km per hour. The highest design speed is now 120 km/h, and its increase calls for a safety check for both operating vehicles and motorists around horizontal curves. Currently, this check is done by comparing the supplied friction values against the required values. The assumption in this check is that vehicles and motorists are safe from having vehicle sliding if the supplied exceeds the required. Whereas considered satisfied for current freeway design speed levels, this assumption is not yet screened for 130-160 km/h speed levels. This research made vehicle speed measurements in three representative horizontal curves with relatively long curve radii in flat terrains located in West Seoline Freeway. The measurements revealed that based on AASHTO design standard motorists seem to experience driving discomfort when negotiating curves at higher than 130 km/h speeds. This finding is informative, and it is recommended that highway engineers pay extra attention when they design this type of curve in future SMART highway.

**Key Words:** *higher design speeds, horizontal curve design, side friction factors, the required, the supplied*

## 1. INTRODUCTION

### 1.1 Background and objectives of the study

Presently a national project of building SMART highway that is a new type of freeway with higher design speed of 130-160 km per hour is underway. SMART highway building and particularly increasing design speed implies motorist's faster driving, and this concerns the public including the law-makers and academics because the maximum design speed in current highway geometric design standards is 120 km per hour that is well below the proposed SMART highway design speed. Motorist safety particularly involves checking the appropriateness of horizontal alignment design standards because horizontal alignment varies more frequently than vertical alignment or cross-section does to reflect surrounding highway conditions. This research thus is limited to reviewing current horizontal alignment standards.

Differently from tangent sections, horizontal curve design theory involves how to deal with centrifugal force generated by fast moving vehicles on the curve. Also, the size of the centrifugal force increases with shorter curves. Therefore, for the safety and comfort of driving motorists, the current design method sets the minimum curve radii for a practical range of highway design speed and requires engineers to apply larger radius than the minimum (8). In the minimum radius calculation, design variables including vehicle operating speed, superelevation, and side friction factor are considered, but among them side friction factor is prevailing. In fact, there are many research findings available for understanding side friction and its characteristics in curve design. For example, Meyer (1949), Barnett (HRB 1936), Moyer & Berry (HRB 1940), and Stonex and Noble (HRB 1940) have published their research findings on side friction values and vehicle speeds made mostly in the US. However, these studies were made in early days of highway design theory development, and it is critical that these research findings, which were based on design speed of 120 km/h at the highest, are not directly applicable to SMART highway design. For instance, J. Emmerson (1969) has calculated actual side friction factors observed at six horizontal curve sites based on passenger car speed data, and found that at the curve radius range of 196-350 m the average value of side friction factors indicated 0.11 with more than 80 % passenger cars having less than 0.15. In contrast, in the case of curve radius range of 70-330 ft, side friction factors were observed to be 0.27 and 0.22 with more than 90 % passenger cars having greater than 0.15. This indicates that observed side friction factors can be different from theoretical values (2). McLean also supported this argument with his finding that motorists experienced higher side friction on curves (7). In summary, it is not desirable to apply the current highway design standards to SMART highway design, and this research has done a review of horizontal alignment design theory and discussed the expected variations of design variables associated with increasing design speed in SMART highway. A field study analysis by measuring vehicle speeds at relatively flat curves in a freeway segment was done to investigate the appropriateness of highway design standards.

The followings are the research objectives:

1. To check the appropriateness of applying current horizontal curve design theory for SMART highway
2. To measure speed levels at very flat curves and calculate actual side friction levels in existing freeways to make a comparison with theoretical values

## **1.2 Research Scope and Approach**

This research has used the following approach. First, existing curve design procedures and their side friction factor values were reviewed for 18 countries over the world to analyze their expected variations at higher speed freeways whose design speed is 130-160 km per hour. Second, to characterize side friction factors at horizontal curves in the higher speed freeways, this research has made a substitution and selected very flat horizontal curves in an existing freeway in West Sealline Freeways in South Korea, and made vehicle speed observations on the curves. Figure 1 illustrates the research approach.

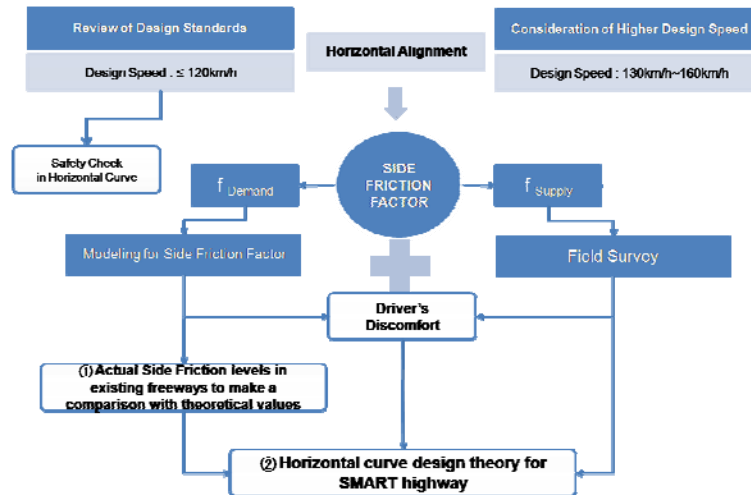


Figure 1 Research Approach

## 2. REVIEW OF SIDE FRICTION FACTORS IN HORIZONTAL CURVE DESIGN

### 2.1 Mass Point Formula

When a vehicle moves in a circular path, it is forced radially outward by centrifugal force. To counterbalance the force and stay moving in the circular path, the friction force that is developed by vehicle weight and friction factor between tires and pavement must be greater than the centrifugal force. In highway geometric design practice, engineers use superelevation for a long time to supplement the friction force and facilitate smoother vehicle travel in a curve (1). In the design of highway curves, there exists the relation between design speed and curvature and also the joint relations with superelevation and side friction (1). And this relation is called the Mass Point formula in highway design.

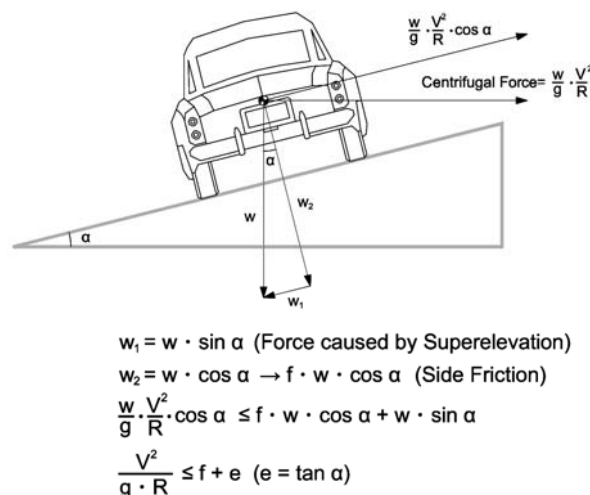


Figure 2 Centrifugal Force in Horizontal Curve

## 2.2 Application of Side Friction Factors

When a vehicle travels and an outside force which acts to the vehicle in perpendicular direction can generate the friction force. In highway curve design this perpendicular force is the centrifugal force discussed in the previous section and the reacting force is the side sliding friction force. The ratio of the side sliding friction force and normal force is called as the side sliding friction factor or the side friction factor in highway curve design. Based on an international survey for the use and measurements of the side sliding friction factor (6,7,8), this value varies depending upon pavement texture and wearing condition and shows: Asphalt cement concrete (0.4-0.8), Cement concrete (0.4-0.6), and icy condition (0.2-0.3).

In highway curve design, there are two design criteria for determining suitable design levels of the side friction factor. First, does the vehicle fail to have a proper side friction level and actually slide on the curve? Second, do motorists feel intolerable levels of discomfort due to centrifugal force while driving the curve? These two side friction factors can have different values, and highway curve design usually adopts the value based on the second method. To determine them, the US and some other nations have made numerous measurements and tests, and Figure 5 summarizes their results (1).

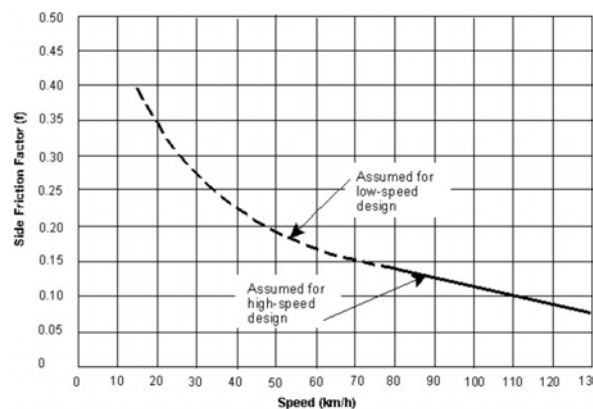


Figure 3 Side Friction Factors for Highway Curve Design

Interestingly, there recently was an initial stage research for establishing highway design standards to be used in higher design speed freeways in the US, and its conclusion included the side friction levels of 0.08-0.04 at the increased freeway speed (3). The authors reviewed this research report and found that they simply utilized the existing relationship between side friction factor and design speed (3). A different approach for measuring side friction factors was adopted in Europe. In Switzerland, 300 sites were selected and a relationship expressing their pavement conditions and side friction force at different speed levels were developed. And based on the relationship two side friction factor equations, one for the longitudinal direction and another for the side direction, were published (8). McLean in Australia asserted based on his empirical analysis that the side friction values specified in AASHTO design guideline were too low. Then he proposed to increase the current side friction values ranging 0.11-0.19 to 0.08-0.35 (7). Meanwhile a group of researchers in Germany including R. Lamm (1999) investigated several European country cases and proposed a new relationship for finding relevant side friction factors in highway curve design as shown in Eqn. (2).

$$f_R = 0.27 - 2.19 \times 10^{-3} V_d + 5.79 \times 10^{-6} (V_d)^2 \quad (2)$$

Where,  $f_R$  : Side Friction Factor

$V_d$  : Design Speed (km/h)

Table 1 Summarize of International Practices of Side Friction Factors in Curve Design

Design Speed (km/h)	Austria	Belgium	Canada	France	Germany	Ireland	Italy	S Korea
50			0.16					0.16
60	0.16	0.16	0.15	0.16	0.14	0.15	0.17	0.14
70	0.15		0.15		0.12			0.13
80	0.14	0.13	0.14	0.13	0.11	0.14	0.13	0.12
90	0.13	0.11	0.13		0.10			0.11
100	0.11		0.12	0.11	0.09	0.13	0.11	0.11
110			0.10					0.10
120	0.10	0.10	0.09	0.10	0.07	0.12	0.10	0.10
Design Speed (km/h)	Luxem bourg	Nether land	Portugal	South Africa	Spain	Sweden	Switzer land	U.S
50				0.16		0.18	0.19	0.16
60	0.16	0.17	0.16	0.15	0.16		0.16	0.15
70	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.14
80	0.14		0.14	0.14	0.14		0.14	0.14
90	0.13			0.13	0.14	0.12	0.13	0.13
100	0.12	0.12	0.12	0.13	0.13		0.12	0.12
110	0.11			0.12		0.10	0.11	0.11
120	0.10	0.08	0.10	0.11	0.10		0.10	0.09

### 3. FIELD STUDY OF SIDE FRICTION FACTORS

At present higher design freeways such as SMART highway do not exist in S Korea. Therefore, to characterize vehicle operating in horizontal curves for higher design freeways, this research selected the most favorable highway sections available in this country and made speed measurements on the selected sections. The selected sections are located in West Sealline Freeway within Kwanchun-Dechun and Buan-Julpo cities. There were 3 horizontal curves in the selected sections with curve radii greater than 2,000 meters and vertical grades of -3 to +3 %. The speed survey was made by subdividing the curves into three different segments and applying both the spot speed measurement and license plate technique. The average speed values were finally utilized as the vehicle speed. In the meantime, this research investigated the as-built plan and profile drawings for each site to get curve radius and superelevation data. Using these field study information and Mass-Point formula explained previously, this research could obtain the available side friction levels experienced by drivers on the curves. Finally the appropriateness of AASHTO design guideline as to side friction factors was reviewed by plotting each side friction values in one drawing as shown in Figure 4. In Figure 4, the horizontal axis indicates the ascending order placement of the speeds measured in this field study with N being the total sample size.

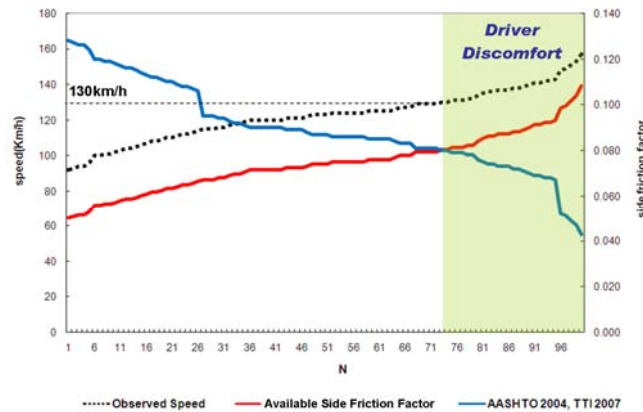


Figure 4 Comparison of  $f_{RM}$  with  $f_{RR}$

The result revealed that actual side friction level experienced by drivers during curve driving would increase with higher speeds. In contrast, in Table 1, the side friction factors, which are maximum side friction factors and developed to promote driver comfort during curve driving, specified in the current highway curve design show a decreasing pattern with speed increase. Therefore, by overlapping these two side friction factors that were obtained by two different methods, one by AASHTO and the other by field measurement in this research, one can be aware of the followings:

- Although the horizontal curves radii in the field study sites were greater than 2 km, measured side friction factors seem to violate AASHTO design side friction factors when motorists driving faster than 130 km/h speed level.
- For some reason, it was found that the superelevation values in the selected curves involved Normal Crown that had negative superelevation values.

Thus, to resolve these problems, the research proposes two approaches. First, a new set of side friction factors being relatively higher than the current values should be developed. This is because even though the natural setting of S Korea is far too different from the one in the US, the current side friction values generally follow the US value. This research decided to look into worldwide practices particularly including European nations, and attempted to develop more reasonable values for highway curve design.

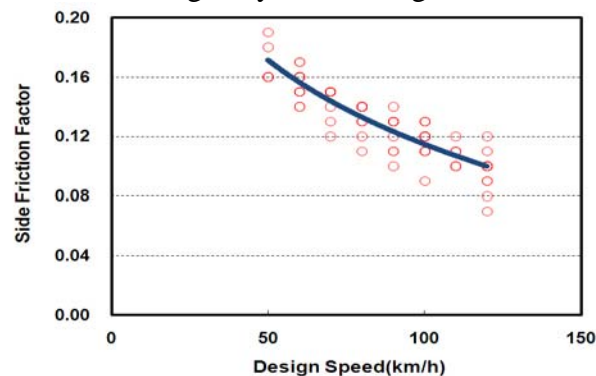


Figure 5 Plotting of Various Side Friction Factors with Design Speed

And the research made an assumption that the model relating side friction factors and design speed would be a logarithmic function. Applying SPSS to the international side friction factors, Eqn. (3) was obtained.

$$f_R' = 0.49 - 0.08 \times \ln(V_d) \quad (3)$$

Where,  $f_R'$ : Side friction factor for this research

$V_d$  : Design speed (km/h)

Table 2 summarizes the statistics of Eqn. (3).

Table 2 Model Summary of Eqn. (3)

Confidence Level	R	R <sup>2</sup>	Adjust R2	Standard Error	t-Statistics	
					Vd	Constant
95%	0.905	0.819	0.817	0.010	-20.401 (0.000)	27.685 (0.000)

Multiple correlation coefficient and determination coefficient indicated 0.905 and 0.819, respectively. The regression equation involved a significantly high power of explanation. Also, t-statistics indicated high significance. Table 3 shows the summary of the analysis of variance, and with F value of 416.21 the regression equation obtained in this research had high significance in explaining the sum of squares for independent variables.

Table 3 Analysis of Variance of Eqn. (3)

	d.f	Sum of Squares	Mean Squares	F	Sig. F
Regression	1	0.0440	0.0440	416.21	0.000
Residual	92	0.0097	0.0001		
Total	93	0.0537			

With this newly developed regression equation of Eqn. (3), side friction factors for different design speeds were calculated and compared with other values including AASHTO, Switzerland, and R. Lamm. Figure 6 exhibits the comparison result.

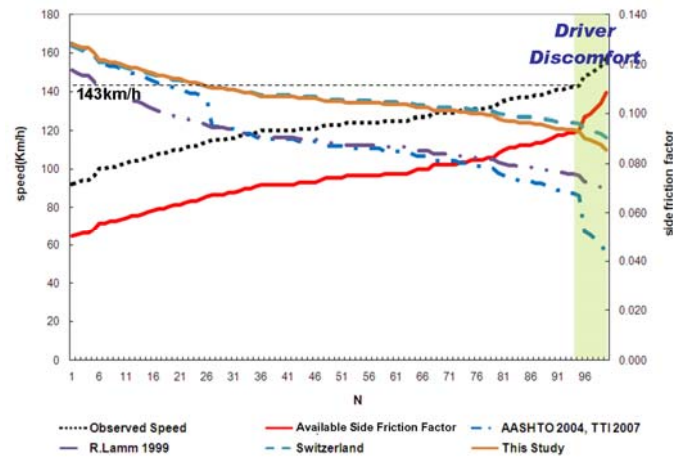


Figure 6 Comparison of  $f_{RM}$  with Revised Side Friction Factors

Applying Eqn. (3), this research discovered that driver discomfort now started to occur at 143 km/h speed level. This speed is 13 km/h higher than the previously found driver discomfort speed level, and it is concluded that in higher speed freeway design a new set of side friction factors, which reflect worldwide highway curve design practice, should be considered.

Next, this research is concerned with superelevation values for the observed sites. For some reason, 0 % superelevation value was applied and observed so in the curves. And this was confirmed in this research by double checking of as-built plan and profile drawings. This is not correct, and this research proposes proper treatments. Applying Eqn. (3), this research determined that whereas with 0% superelevation, driver discomfort occur if driving faster than 152 km/h, with proper superelevation design driver discomfort starts only when driving faster than 160 km/h. This implies that proper superelevation application is such an important design element that engineers should pay extra attention in its application in higher speed freeway design.

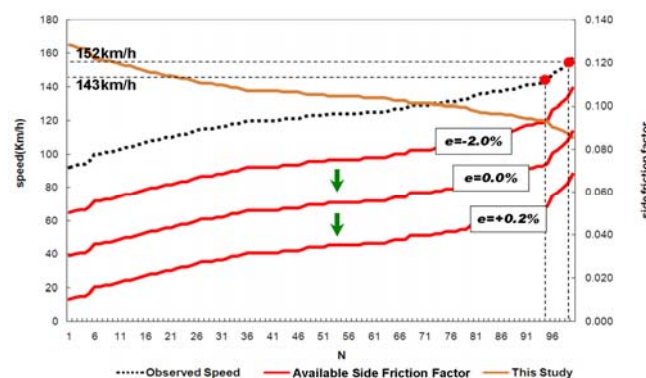


Figure 7 Variation of Driver Discomfort in Highway Curves by Superelevation Values

#### 4. CONCLUSION



In this research the existing curve design procedures and their observed side friction factor values in selected field sites in South Korea were reviewed for preparing to build higher speed freeways. And the followings were found in this research:

- Although the horizontal curves radii in the field study sites were very large with more than 2 km, actual measuring vehicle speeds and calculating side friction factors in this research revealed that applying AASHTO design side friction factors in South Korea may lead to poor design when motorists driving faster than 130 km/h speed level.
- By revising side friction factor values to reflect international practices, this research discovered that driver discomfort now started to occur at 143 km/h speed level, a speed level that is 13 km/h higher than the previously found driver discomfort speed level
- Also, this research determined that whereas with 0% superelevation driver discomfort would occur when driving faster than 152 km/h, with proper superelevation design driver discomfort starts to occur only when driving faster than 160 km/h. This implies that proper superelevation application is such an important design element that engineers should pay extra attention in its application particularly in higher speed freeway design.

## REFERENCE

- AASHTO(2004), **A Policy on Geometric Design of Highways and Streets-5th edition**, American Association of State Highway and Transportation Officials, America, Washington D.C.
- Emmerson, J (1969), Speeds of Cars on Sharp Horizontal Curves, **Traffic Engineering and Control**
- K. Fitzpatrick, K. Zimmerman, R. Bligh, S. Chrysler, and Byron Blaschke (2007), **Criteria For High Design Speed Facilities**, Texas Transportation Institute, America
- Lamm R, Basil P., Theodor M.(1999), **Highway Design and Traffic Safety Engineering Handbook**, McGraw-Hill Professional Publishing
- Lamm R , Choueiri, E , Mailaender, T(1991), Side friction Demand Versus Side Friction Assumed for Curve Design on Two-Lane Rural Highway, **Transportation research record**, No. 1303, 11-21
- Lamm R, A.K. Guenther, E.M. Choueiri(1995), Safety Module for Highway Geometric Design, **Transportation Research Record**, No. 1512, 7-15
- McLean, J. R ,(1983), Speeds on Curves : Side Friction Factor Considerations, **Research Report ARR**, No. 126
- MOCT (2000), **Highway Geometric Design Standards and Regulation**, Ministry Of Construction and Transportation, South Korea
- Peter Spacek (2004), Influence of Speeds on Design Standards in Switzerland, **Transportation Research Record**, No. 1881, 19-26